EVS-25
Shenzhen, China, Nov. 5-9, 2010

Fuel Cell Hybrid Taxi Well-to-Wheel Life-Cycle Analysis

Patricia Baptista[1,*], João Ribau[1], João Bravo[1], Carla Silva[1], Paul Adcock[2], Ashley Kells[2]

[1] *IDMEC - Instituto Superior Técnico, UTL, Av. Rovisco Pais, 1 - 1049-001 Lisboa – Portugal*

[2] *Intelligent Energy, Charnwood Building, Holywell Park, Ashby Road, Loughborough, LE11 3GR, UK*

[*] *Corresponding author e-mail: patricia.baptista@ist.utl.pt*

Abstract

In a collaboration led by hydrogen fuel cell developer Intelligent Energy, a fleet of classic London cabs fitted out with hydrogen fuel cell power systems will be produced, with the objective of having a small fleet ready for full road trials in time for the 2012 Olympics. This research develops the Well-to-Wheel (WTW) Life-Cycle Analysis (LCA) for two hydrogen powered vehicle powertrain options (fuel cell plug-in hybrid vehicle, PHEV-FC; and fuel cell hybrid vehicle, HEV-FC), in comparison to the conventional ICE Diesel Taxi and a full electric vehicle (EV). In terms of energy pathways, the introduction of these different vehicle technologies is associated with alternative energy sources in a Taxi fleet so the following fuel pathways are compared: diesel, considering the average European diesel fuel characteristics; electricity, considering the 2008 UK electricity generation mix; and hydrogen, considering the compressed hydrogen option from centralized natural gas reforming. This Well-to-Wheel analysis combines the Tank-to-Wheel (TTW), which accounts for the emissions and fuel consumption that result from moving the vehicle through its drive cycle, with the Well-to-Tank (WTT), which accounts for the fuel production stage. For the European certification driving cycle (NEDC), the PHEV-FC Taxi resulted in the lower WTW energy and CO_2 emissions results (2.99 MJ/km and 159 g/km), followed by the HEV-FC Taxi (3.28 MJ/km and 174 g/km), and by the EV (3.21 MJ/km and 173 g/km), compared to the ICE Diesel (3.60 MJ/km and 280 g/km). For a more demanding London driving cycle a 33, 28, 54 and 154% increase in the WTW energy consumption and CO_2 emissions is observed for the PHEV-FC Taxi, HEV-FC Taxi, EV and ICE Diesel respectively.

Keywords — London Taxi, fuel cell hybrid vehicle, life cycle analysis, energy consumption, CO_2 emissions.

1. Introduction

The concept of electrifying the transport sector has grown over the last couple of years by the possibility of an increasing penetration of electricity powered vehicles such as hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and full electric vehicles (EV). The combination of these solutions with the use of hydrogen allied is also an important prospect.
These technologies are addressed as possible ways of reducing the dependency on fossil energy and of decreasing CO_2 emissions [1] and are being developed by several car manufactures. Their advantages increase especially with the introduction of renewable sources in electricity generation or hydrogen production.
When comparing different vehicle technologies the most adequate methodology includes a Life-Cycle Analysis (LCA) methodology which focuses on a product's flows during all its lifetime. A certain vehicle technology powered by a specific fuel must include in its LCA not only its utilization stage related to driving the vehicle, Tank-to-Wheel (TTW), but also the fuel production stage, Well-to-Tank (WTT), and the vehicle itself manufacturing, maintenance and recycling, Materials Cradle-to-Grave (CTG) [1].
More specifically, EVs are only powered by the battery pack stored electricity, which is discharged providing energy to the electrical motor that drives the vehicle wheels. Additionally, on deceleration events typically 10% of rear braking energy can be recovered (or 40% if front braking) and re-stored in the battery. The battery is depleted until it reaches a minimum state-of-charge (SOC), usually 20% to assure proper battery functioning [2]. EVs locally in their TTW stage they do not produce atmospheric pollutants.
As for HEV, they are powered, in a series configuration, by the primary power source which can be an internal combustion engine (ICE) or a fuel cell

(FC) that drives a generator or an electrical motor that move the wheels of the vehicle. For an ICE, the electric power from the generator is stored in the batteries and is used to power the electric traction motor that drives the wheels. In some parallel systems the ICE and the electric motor share the same shaft, one cannot turn without the other. In other parallel configurations the primary energy source can drive a generator as in a series system but it can also drive the vehicle alongside (or parallel to) the electric traction motor (full hybrid).

PHEV combines the HEV with the EV configurations. In addition to the EV configuration, its batteries can be recharged directly from the additional power source. This power source can be an ICE or a fuel cell pack to power the electric motor and/or power the battery pack, which is regarded as a range extender to increase the vehicle's range without being recharged. PHEVs are designed to use a charge depleting strategy for the battery (CD mode) discharging the battery until it reaches a minimum state-of-charge (SOC) that can be 30–45% [2] depending on battery and powertrain configuration. After reaching this minimum SOC, a charge sustaining strategy of the battery (CS mode) is enrolled, in similarity to the conventional hybrids sustaining strategy. The additional power source is used to help propulsion and provide additional range. As previously mentioned, one of the possibilities for the auxiliary power unit is a fuel cell. A fuel cell is composed by a stack of cells connected in series. Usually, fuel cells are named according to its electrolyte and the temperature it operates. Proton Exchange Membrane (PEM) is the most common in road vehicle applications.

Regarding the battery packs for both PHEV and EV, the tendency is to use lithium based batteries [3]. In terms of braking energy potential, it round again 10% of rear braking energy (or 40% if front braking).

Considering the energy source pathway for electricity powered vehicles, an electricity recharging infrastructure will have to be deployed. Electricity is not a primary energy source, but an energy carrier, since electricity is produced using other primary energy resources prior to the utilization stage, which means that electricity has global emissions associated to its production.

In the case of hydrogen powered vehicles, the problem of an infrastructure and upstream energy consumption and emissions also occurs. That is why the majority of demonstration projects are related to the public bus sector, such as the Clean Urban Transport for Europe (CUTE), the Global Hydrogen Bus Platform (HyFLEET:CUTE), the Sustainable Transport Energy Programme (STEP) and the Ecological City Transport System (ECTOS) [4]. However, some original equipment manufacturers (OEM) of light-duty vehicles have already engaged prototype developing. Some of those prototypes out of more than 20 are: Mercedes-Benz F600 Hygenius (hybrid), Honda FCX (hybrid), GM Chevy Volt Hydrogen (plug-in hybrid) and Ford Edge with HySeries Drive (plug-in hybrid). There are two possible ways of using hydrogen to power a vehicle: by burning the hydrogen directly leading to some pollutants emissions, such as nitrogen oxides (NO_x); or by using fuel cells, which only produce water vapor.

This paper studies the application of a hydrogen fuel cell power systems applied to the classic London Taxis that is being led by hydrogen fuel cell developer Intelligent Energy (IE), applying a life-cycle analysis. An ICE diesel vehicle, a plug-in hybrid electric fuel cell vehicle (PHEV-FC), a hybrid electric fuel cell vehicle (HEV) and an EV are compared in terms of energy consumption and CO_2 emissions.

2. Methodology

To better understand how road vehicle technologies energy consumption and CO_2 emissions compare, a full life cycle perspective is usually used. However, in this specific case the focus was given to the TTW and WTT components since the main objective was to compare the different powertrains behavior and the different energy pathways associated, excluding the influence of the vehicle production for this demonstration project.

Regarding the TTW stage, for simulating the daily commuting journeys of conventional or alternative vehicle technologies the software Road Vehicle Simulation (RVS) [5] was used. RVS is a result of EcoGest [6] upgrade within a PhD program and is similar to the mostly used commercial software ADVISOR [7] although the main input variables are commonly available, allowing to simulate, through its database, more types of alternative fuels (biodiesel, ethanol, natural gas, hydrogen, LPG), including engine fuel consumption and emissions map generation [8]. The main advantage is the more controllable and easiness of programming new powertrain configurations and strategies.

The general mobility parameters and driving conditions for the Taxi consider are around 550000 km of Taxi lifetime kilometers traveled and average passenger occupancy of 1.48 [9].

The PCO-CENEX London Taxi driving cycle [10] (Figure 1) is considered representative of the London Taxi driving conditions. It has three distinct phases with different durations and average speeds, including also a key off period. The vehicles were also tested in additional standard driving cycles: the New European Driving Cycle (NEDC) and the Highway Fuel Economy Driving Cycle (HWFET).

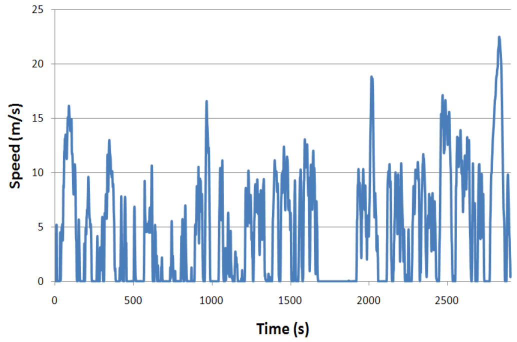


Figure 1: Speed profile for the PCO-CENEX London Taxi driving cycle.

The general vehicle characteristics, which were maintained for the four vehicle configurations, correspond to a 2.78 m^2 vehicle frontal area, 0.46 drag coefficient, 0.325 m tire rolling radius, 0.014 rolling coefficient [11] and 1000 W accessory power. The main assumptions used to characterize the different vehicle technologies were the following:

- ICE (Diesel): internal combustion engine vehicle running on diesel, with a curb weight of 1895 kg and a diesel engine with 75 kW. The transmission is 5-speed with the following gear ratios: 3.00, 1.67, 1.0, 0.75, 0.67 and the final drive ratio is 4.1.
- Plug-in hybrid (PHEV-FC, hydrogen and electricity) or hybrid (HEV-FC, hydrogen): series hybrid with fuel cell and a curb weight of 2060 kg. Fuel cell stacks peak power 32 kW (limit of response ±10000 W/s), electric motor 100 kW and a lithium battery 13.96 kWh [12].
- Full electric vehicle (EV) with a curb weight of 2834 kg, electric motor 100 kW and a lithium battery 155.9 kWh. This configuration discharges the battery up to 20% SOC at the daily use.

For the PHEV-FC vehicle, the fuel cell is only OFF above the 80% SOC and below the 10 kW power required; for other power and SOC combinations the FC in ON following load and at least ON in the maximum efficiency (2.6 kW point). The HEV-FC vehicle, where the plug-in option is not available, considers that the fuel cell is only OFF above the 80% SOC and below the 10 kW power required; otherwise the fuel cell follows load trying to bring SOC to 95% with its minimum functioning power level corresponding to the maximum efficiency point of the fuel cell.

For the PHEV-FC, a daily recharging pattern is considered for electricity before the 15 hours of typical daily usage in the PCO-CENEX London. The PHEV-FC considers that the Taxi has the option of recharging the batteries in an outlet, so the batteries are discharged up to around 40% SOC and then maintain that SOC. As for the HEV, no plug-in option is considered, so fuel cell follows load with its minimum functioning power level corresponding to the maximum efficiency point of the fuel cell.

Regarding WTT, data from the UK Department of Energy and Climate Change [13] and from the Institute for Environment and Sustainability of the European Commission Joint Research Centre [14] was used. The total energy of the WTT pathways (MJ_{ex}) does not include the energy content of the produced fuel, so it is the WTT expended energy.

For the diesel fuel specific data for UK was not found. A reference value for Europe was used [14]. The diesel WTT accounts for Crude Extraction & Processing; Crude Transport; Refining; and Distribution and dispensing (see Table 1).

Table 1: Diesel pathway for Europe

Process	Energy (MJ_{ex}/MJ_{fuel})	CO_2 (g/MJ_{fuel})
Extraction & Processing	0.03	3.7
Transport	0.01	0.9
Refining	0.10	8.6
Distribution & Dispensing	0.02	1.0
Total pathway	**0.16**	**14.2**

For electricity UK specific data, the grid distribution losses, the electricity generation efficiencies and generated CO_2 were accounted for. The grid distribution losses are on average 7.6% [13]. The electric generation mix and efficiencies were also taken into account. CO_2 emissions in 2008 are reported to be 497 t/GWh [13]. The estimated energy and CO_2 emissions WTT factors for the UK are 1.77 MJ_{ex}/MJ_{fuel} and 149 g/MJ_{fuel} respectively (see Table 2).

Table 2: UK-mix WTT factor for energy and CO_2 emissions.

Process	UK	
	Energy (MJ_{ex}/MJ_{fuel})	CO_2 (g/MJ_{fuel})
UK-mix power generation	1.69	149.4
Distribution	0.08	0
Total pathway	**1.77**	**149.4**

For the hydrogen, centralized natural gas reforming is assumed. Some specific data for UK concerning natural gas origin and reference values for Europe were used [14]. The option of compressed gaseous hydrogen (CH_2) was chosen (see Table 3). In terms of natural gas origin, it was considered 99% share of compressed natural gas (CNG) via pipeline and 1% liquefied natural gas (LNG) via ship in UK [13].

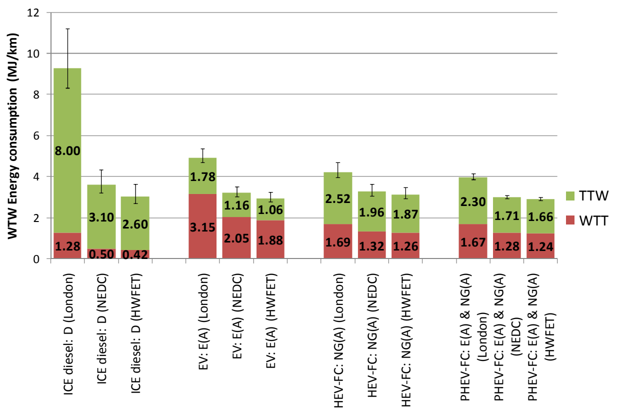
Table 3: WTT energy and CO_2 emission factors for hydrogen Pathway CH_2.

Pathway CH_2		
Share: 99%	**Energy (MJ_{ex}/MJ_{fuel})**	**CO_2 (g/MJ_{fuel})**
Extraction & Processing	0.04	1.6
Transport 1000 km-4000 km pipeline	0.08	4
Distribution	0.01	0.7
Central Reforming	0.32	73.7
Gaseous H_2 distribution & compression	0.22	8.5
-	-	-
Share: 1%	**Energy (MJ_{ex}/MJ_{fuel})**	**CO_2 (g/MJ_{fuel})**
Extraction & Processing	0.03	1.6
NG liquefaction	0.11	6.1
LNG Transport (ship)	0.11	7.3
LNG receipt + Vaporisation	0.04	2.4
Central Reforming	0.32	72.6
Gaseous H_2 distribution & compression	0.22	8.5
Total share 100%	Energy (MJ_{ex}/MJ_{fuel})	CO_2 (g/MJ_{fuel})
Total pathway #1	**0.67**	**88.7**

3. Results

The results in terms of TTW and WTT energy consumptions and CO_2 emissions are presented in Figure 2.

a)



b)

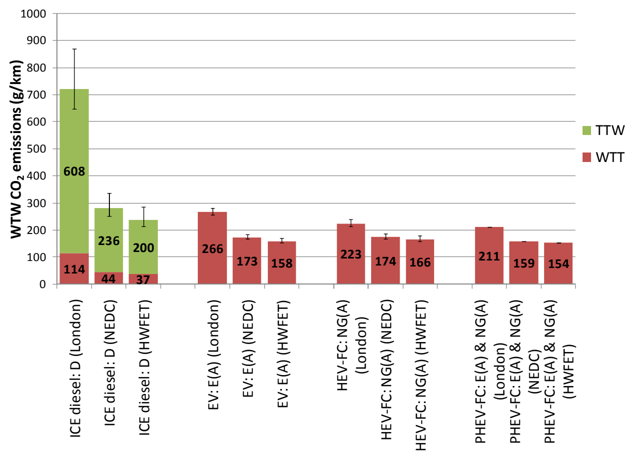


Figure 2: WTW energy consumption a) and CO_2 emissions b) results for the three considered vehicle technologies.

Table 4 and Table 5 present the WTW aggregate results for the different vehicle technologies in the three tested driving cycles.

Table 4: Summary of energy consumption results for the different vehicle technologies in WTW analysis for the three tested driving cycles.

Taxi	**Driving cycle**	**WTW Energy consumption (MJ/km)**		
		average	**min.**	**max.**
ICE Diesel	PCO-CENEX London	**9.28**	8.32	10.24
	NEDC	**3.60**	3.22	3.97
	HWFET	**3.02**	2.70	3.33
PHEV-FC: E(A) & NG(A)	PCO-CENEX London	**3.97**	3.73	4.16
	NEDC	**2.99**	2.82	3.13
	HWFET	**2.90**	2.73	3.03
HEV-FC: NG(A)	PCO-CENEX London	**4.21**	3.95	4.43
	NEDC	**3.28**	3.07	3.44
	HWFET	**3.13**	2.93	3.29
EV: E(A)	PCO-CENEX London	**4.93**	4.84	5.02
	NEDC	**3.21**	3.16	3.27
	HWFET	**2.94**	2.88	2.99

Table 5: Summary of CO_2 emissions results for the different vehicle technologies in WTW analysis for the three tested driving cycles.

Taxi	**Driving cycle**	**WTW CO_2 emissions (g/km)**		
		average	**min.**	**max.**
ICE Diesel	PCO-CENEX London	**722**	648	797
	NEDC	**280**	252	309
	HWFET	**237**	213	262
PHEV-FC: E(A) & NG(A)	PCO-CENEX London	**211**	203	218
	NEDC	**159**	153	164
	HWFET	**154**	148	159
HEV-FC: NG(A)	PCO-CENEX London	**223**	214	232
	NEDC	**174**	167	180
	HWFET	**166**	159	172
EV: E(A)	PCO-CENEX London	**266**	266	266
	NEDC	**173**	173	173
	HWFET	**158**	158	158

For all vehicle technologies, the PCO-CENEX London driving cycle presents higher TTW energy consumption and consequently CO_2 emissions than the standard driving cycles, since it is a very aggressive cycle (having an higher absolute average acceleration of 0.5 $m.s^{-2}$ compared with 0.25 $m.s^{-2}$ for NEDC).

As expected the ICE Taxi has the highest energy consumption value per kilometer. By introducing the PHEV-FC, HEV-FC or EV technologies, the London Taxi energy consumption can be reduced up to 3 to 4 times and local (TTW) CO_2 emissions can be eliminated.

When the TTW results are combined with WTT, obtaining the WTW results, the diesel vehicle technology is clearly worse with higher energy and CO_2 emissions values. It is followed by the EV Taxi that, in spite of not having a TTW component, has a considerable WTT value. This is partly due to the considerable amount of weight and volume that must be added to the vehicle if a EV version of the Taxi is to be considered (c.a. 38% weight addition), in order to maintain the daily usage patterns of the vehicle and a final battery SOC of 20%,. Even with such weight the EV TTW energy consumption presents reasonable results, due to its high efficiency (average efficiency for EV is 77% and for PHEV-FC is only 40%). However, it will require a charging point capable of 14 kVA to maintain a daily charge time of less than 9 hours. In addition, it is also likely that the cost will be far greater than the PHEV-FC solution, which is an important consideration given that the vehicle is used as a business tool.

Both fuel cell taxi technologies with compressed hydrogen from centralized reforming have a combination of best energy and CO_2 values. The PHEV-FC vehicle technology using compressed hydrogen presents the lower combined WTW results both for energy and CO_2 emissions (3.97 MJ/km and 211 g/km).

The fuel pathways energy efficiency is on average 86% for diesel, 35% for electricity and 53% for hydrogen. Analyzing the disaggregated results between TTW, and WTT a shift in energy consumption and emissions is clear. If for the ICE Diesel TTW account for 86% and 84% energy and CO_2 emissions respectively of the WTW, choosing a FC vehicle Taxi reduces the importance of TTW up to around 60%/0% (energy/CO_2) and in case of an EV up to 36%/0% (energy/CO_2). The WTT importance in the ICE Diesel WTW shifts to higher values in the alternative powertrains, from 14%/16% to 40%/100% (energy/CO_2) for the FC vehicle and 64%/100% (energy/CO_2) for the EV, since we are shifting the energy consumption from the transportation sector to hydrogen or electricity production.

4. Conclusions

A WTW life cycle analysis of possible alternative vehicle technologies for the traditional London Taxi was performed regarding its energy consumption and CO_2 emissions results. The comparison between an ICE diesel vehicle, a plug-in hybrid electric fuel cell vehicle (PHEV-FC), a hybrid electric fuel cell vehicle (HEV-FC) and an EV was performed. For the European certification driving cycle (NEDC), the PHEV-FC Taxi resulted in the lower WTW energy and CO_2 emissions results (2.99 MJ/km and 159 g/km), followed by the HEV-FC Taxi (3.28 MJ/km and 174 g/km), and by the EV (3.21 MJ/km and 173 g/km), compared to the ICE Diesel (3.60 MJ/km and 280 g/km). For a more demanding London driving cycle a 33, 28, 54 and 154% increase in the WTW energy consumption and CO_2 emissions is observed for the PHEV-FC Taxi, HEV-FC Taxi, EV and ICE Diesel respectively.

This demonstrates that a hydrogen fuel cell powered solution for the conventional London Taxis can provide the lowest energy consumption, least CO_2 production and will emit zero emissions at the point of use.

Acknowledgments

The authors would like to acknowledge the sponsor of the research: Intelligent Energy. Thanks are also due to MIT Portugal Program and Fundação para a Ciência e Tecnologia for the PhD financial support (SFRH/BD/35191/2007 and SFRH/BD/27736/2006) and national project MIT-Pt/SES-GI/0008/2008.

References

1. Baptista, P., Tomás, M., Silva, C., *HYBRID PLUG-IN FUEL CELL VEHICLES MARKET PENETRATION SCENARIOS.* International Journal of Hydrogen Energy, 2010. xxx: p. 1-7.
2. Larminie, J., Lowry, J., *Electric Vehicle Technology Explained*, ed. J.W. Sons. 2003: John Wiley & Sons.
3. Ehsani, M., Gao, Y., Emadi, A., *Modern Electric, Hybrid Electric and Fuel Cell Vehicles - Fundamentals, Theory, and Design*. 2nd Editions ed. 2010: CRC Press.
4. J. Ally., T.P., *Life-Cycle assessment of diesel, natural gas and hydrogen fuel cell bus transportation systems.* Journal of Power Sources, 2007. 170: p. 401-411.
5. Gonçalves, G., Bravo, J., Baptista P., Silva C. and Farias T., *Monitoring and Simulation of Fuel Cell Electric Vehicles.* World Electric Vehicle Journal, 2009. 3.
6. Silva, C.M., Ross, M., Farias, T. L., *Analysis and simulation of "low-cost" strategies to reduce fuel consumption and emissions in conventional gasoline light-duty vehicles.* Energy Conversion and Management, 2008. 50(2): p. 215-222.
7. Wipke, K., Cuddy, M., Burch, S., *ADVISOR 2.1: A User Friendly Advanced Powertrain Simulation Using a Combined Backward/Forward Approach.* IEEE Transactions on Vehicular Technology, 1999(48): p. 1751-1761.
8. Bravo, J., Silva, C., Farias, T., *Road Vehicle Simulation Model for Energy and Environmental Impact of Petrodiesel and Biodiesel.* Clean Air, 2007. 8(4): p. 1-19.
9. Available from: http://www.tfl.gov.uk/corporate/modesoftransport/7311.aspx.
10. CENEX, *Public Carriage Office and Cenex Publish New Low Emission Test Cycle for London Taxis.* November 2009.
11. Bosch, ed. *Bosch Automotive Handbook.* Vol. 7th Edition. 2007. p430.
12. Kokam, *Cell Specification [SLPB 100216216H_40Ah]*. 2008.
13. MacLeay, I., Harris, K., Annut, A., et al., *Digest of United Kingdom Energy Statistics 2009*. 2009, UK Department of Energy and Climate Change.
14. Edwards, R., Griesemann, J-C., Larivé, J-F., Mahieu, V., *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context.* 2008, Concawe, JRC, EUCAR.

Authors

Patrícia Baptista
IDMEC - Instituto Superior Técnico, UTL, Av. Rovisco Pais, 1 - 1049-001 Lisboa – Portugal
Email: patricia.baptista@ist.utl.pt
Patrícia C. Baptista received the Chemistry degree (five-year course) in 2006 from Instituto Superior Técnico, Technical University of Lisbon, Portugal. She is currently pursuing the Ph.D. degree in Sustainable Energy Systems from Instituto Superior Técnico within the MIT Portugal Program. Her main research interests are on the impacts of alternative vehicle technologies and energy sources on the Portuguese road transportation sector.

João Ribau
IDMEC - Instituto Superior Técnico, UTL, Av. Rovisco Pais, 1 - 1049-001 Lisboa – Portugal
Email: joao.ribau@ist.utl.pt
João P. Ribau received the Mechanical Engineering Bologna master´s degree from the Technical University of Lisbon, Instituto Superior Técnico, Portugal, in 2009. Currently he´s a researcher at IDMEC Institute of Mechanical Engineering at IST, under the MIT-Portugal project "Power demand estimation and power system impacts resulting of fleet penetration of electric/plug-in vehicles". Areas of interest are vehicle technology, and logistics of energy supply.

João Bravo
IDMEC - Instituto Superior Técnico, UTL, Av. Rovisco Pais, 1 - 1049-001 Lisboa – Portugal
Email: joao.bravo@ist.utl.pt
João T. Bravo received the Mechanical Engineering degree (five-year course) in 2006 from Instituto Superior Técnico, Technical University of Lisbon, Portugal. He is currently pursuing the Ph.D. degree in Mechanical Engineering from Instituto Superior Técnico. His main research interests are simulation of alternative vehicle technologies and energy sources on the Portuguese road transportation sector.

Carla Silva
IDMEC - Instituto Superior Técnico, UTL, Av. Rovisco Pais, 1 - 1049-001 Lisboa – Portugal
Email: carla.silva@ist.utl.pt
Carla M. Silva received the Mechanical Engineering degree (five-year course) in 2000 and the PhD degree in Mechanical Engineering in 2005, both at Instituto Superior Técnico, Technical University of Lisbon, Portugal. She went for a post doc at both IST and University of Michigan working on CO2 mitigation in road vehicles. Currently she is a research assistant at IDMEC-Institute of Mechanical Engineering at IST. Areas of interest are new technologies and alternative fuel vehicles simulation; life-cycle analysis and projections.

Paul Adcock
Intelligent Energy, Charnwood Building, Holywell Park, Ashby Road, Loughborough, LE11 3GR, UK
Email: paul.adcock@intelligent-energy.com
Paul Adcock has a B.Sc. in Electronic Engineering, a Ph.D. in Electromechanical Engineering and is a Fellow of the Institution of Engineering and Technology. He has over 20 years experience in developing fuel cell technology and has published over 65 technical papers. He was previously director of the Fuel Cell Group at Loughborough University and prior to this was Chief Electrical Engineer at Regulateurs Europa Ltd.

Ashley Kells
Intelligent Energy, Charnwood Building, Holywell Park, Ashby Road, Loughborough, LE11 3GR, UK
Email: ashley.kells@intelligent-energy.com
Dr. Kells is Senior Programme Manager at Intelligent Energy where he oversees and manages the development of Intelligent Energy's evaporatively cooled fuel cell system products. He holds a B.Eng. and Ph.D. in Automotive Engineering and is a Fellow of the Institution of Mechanical Engineers.